METHOD AND DEVICE FOR WELDING THERMOPLASTIC SYNTHETIC MATERIALS USING LASER LIGHT

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The laser light wavelength is 1.6-2.4 mu m. An Independent claim is included for the corresponding welding equipment. Preferred features: The wavelength is preferably 1.8-2.2 mu m. Two plastic workpieces are welded flatly together, laser light being directed at right angles to the interface. Workpieces are butt-jointed and welded together, laser light being directed towards the joint on both workpieces. The workpieces are clamped during welding, near the joint; at least one jaw transmitting laser light. The workpieces are alternatively unconfined during welding. The laser light is brought to the workpiece through an optical conductor (4), for spot welding. The light can be beamed over a larger, flat area where the weld is to be made.

The invention relates to a method for welding thermoplastic synthetic materials using laser light, wherein the laser light is directed into a welding region of a workpiece or a plurality of workpieces adjoining one another composed of thermoplastic synthetic material. The invention relates, furthermore, to a device for welding thermoplastic synthetic materials by means of laser light according to the method using a laser as light source for the laser light and using an optical system and/or a waveguide for directing the laser light into a welding region of a workpiece or a plurality of workpieces adjoining one another composed of thermoplastic synthetic material.

Welding of thermoplastic synthetic materials is usually done by having the thermoplastic synthetic materials make contact with heating elements. By means of heat transfer from the heating elements to the thermoplastic synthetic materials the latter are heated up and plasticised until, for example, a joint between two workpieces composed of thermoplastic synthetic material is possible. In doing so there is a disadvantage in that the thermoplastic synthetic materials reach their highest temperature at their boundary surface relative to the heating elements, ie are plasticised to a particularly great extent. Plasticisation of the synthetic material, however, is really needed at points where, for example, a joint should be made between two workpieces. On the contrary, in the region of contact with the heating elements there is the danger that on removing the heating elements from the workpieces the workpieces which are still plastic there will be damaged. Accordingly, it is necessary in numerous applications to cool the heating elements first of all and only then to remove them from the workpieces. As a result of this, however, the cycle times achievable in welding are considerably prolonged. Another disadvantage of welding thermoplastic synthetic materials using

heating elements lies in the fact that for constructing welded joints of geometrically complicated shapes heating elements of correspondingly complicatedly shapes are needed and for small-scale or one-off production this is scarcely profitable.

In a method of the type described at the outset disclosed in DE 42 25 679 A1 laser light from a CO_2 laser having a wavelength of 10.6 µm is used. The laser light replaces a heating element and heats up the thermoplastic synthetic material directly. However, laser light having a wavelength of 10.6 µm does not appreciably penetrate into the depth of a workpiece composed of thermoplastic synthetic material even if the synthetic material is transparent in the wavelength range of visible light. On the contrary, after penetrating a few tenths of a mm into the workpiece laser light of wavelength 10.6 µm is completely absorbed and converted into heat. This means that as when using a heating element the heat accumulates in the region of the surface typically facing away from the weld joint in the workpiece facing towards the laser. Since the laser light can act on thermoplastic synthetic material without contact there is no risk of damaging the workpiece on removing a heating element. After welding, however, the workpiece must nevertheless be cooled so that its surface which is particularly plastic in part due to the heating and hence sensitive is not damaged. This is just as contrary to short cycle times for welding as the transfer of heat from the surface of the workpiece into the region of the actual weld. Furthermore, in the known method it is disadvantageous that the devices needed to carry it out are very costly. CO_2 lasers are already expensive per se. To this is added the fact that at present no suitable waveguides for laser light having a wavelength of 10.6 µm are known. Accordingly, laser light of this wavelength must be directed onto the workpiece in question by means of complicated articulated arms bearing mirrors.

From DE 38 13 570 A1 it is in principle known in a method for welding thermoplastic synthetic materials using laser light to select the wavelength of the laser light so that complete absorption of the laser light in the work pieces in question occurs. At the same time, however, specific wavelengths for the laser light are not given.

DE 44 32 081 A1 in a method for welding thermoplastic synthetic materials using laser light discloses the use of laser light having a wavelength of 0.50 to 10.90 µm. In doing so a wavelength range of 0.7 to 3.0 µm is to be particularly preferred. For this preferred wavelength range a Nd-YAG laser is cited exclusively as an example whose laser light is known to have a wavelength of 1.06 µm. Laser light of this wavelength is absorbed only in small proportions by known thermoplastic synthetic materials without additives. Accordingly, in order to achieve high conversion of the laser light into heat one of the two workpieces must be non-transparent at the wavelength of 1.06 µm or a black surface arranged behind the workpieces must be provided. At the boundary surface in question to the transparent synthetic material the laser light is converted into heat. When there is an additional black surface the same disadvantages arise as for a heating element heated in a different way. In a combination of a workpiece made of thermoplastic synthetic material without additives which is transparent to light having a wavelength of 1.06 µm and a workpiece composed of thermoplastic synthetic material which due to additives is not transparent at just this wavelength although in a planar joint between the two workpieces there is a concentration of heat conversion in the area of actual welding, welding of two workpieces in a butt joint, for example, is not possible. Moreover, due to the need to construct a workpiece of thermoplastic synthetic material which

is not transparent at the relevant wavelength there are serious limitations in the applicability of the known method.

DE 25 44 371 discloses the welding flat to one another of very thin films of thermoplastic synthetic material approximately 15 µm thick using laser light having a wavelength of 10.6 µm. For this purpose the laser light is directed through the sheets of thermoplastic synthetic material onto an underlay bar. Given the short absorption length of laser light of this wavelength in thermoplastic synthetic materials this is possible only for films of low thickness. The underlay bar is heated by the laser light to a temperature of almost 1,900 °C at which it emits radiation in the spectral range of 1.7 to 3.4 µm. This radiation should then be adequately absorbed by the synthetic material, which is a polyethylene, although the absorption length of light in synthetic material is greater for shorter wavelengths than for the original laser light having a wavelength of 10.6 µm. Thus, in fact only a very limited portion of the incident light energy is usable for heating the relevant area of the film. Furthermore, due to the high temperature of the underlay bar when welding the films any contact with it must be prevented in costly manner. In such an arrangement it is not possible under any circumstances to concentrate the thermal radiation of a hot underlay bar in the spectral range of 1.7 to 3.4 µm onto a limited welding area since the areas of the underlay bar heated by the original laser light act as point light sources emitting in all free directions in space.

DE 296 21 859 U1 discloses a diode-pumped laser whose crystal can be a Tm: YAG crystal, a Tm, Ho: YAG crystal, a Tm: YLF crystal or a Tm, Ho: YLF crystal and which has a wavelength of the emitted laser light of approximately 2 µm. The laser light can be fed into a low-water or water-free light waveguide, in

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particular into a quartz-quartz fibre. At wavelengths in the region of 2 µm quartz-quartz fibres have such a high transmission coefficient that it is possible to guide the laser light with little attenuation over relatively long fibre lengths of 1 to 3 m.

The invention is based on the object of demonstrating a method for welding thermoplastic synthetic materials of the type described at the outset which allows troublefree and rapid welding even of relatively thick workpieces made of synthetic material with formation of durable welded joints, in particular of butt joints. Furthermore, a device for carrying out the method is to be revealed.

In the method of the type described at the outset the task is solved according to the invention in that the laser light has a wavelength of 1.8 to 2.2 µm, ie of approximately 2 µm. Laser light in this wavelength range is absorbed by many thermoplastic synthetic materials directly, ie independently of any fillers or additives, over an absorption length of a few mm. This means that a workpiece irradiated with laser light of this wavelength is heated at depth and possibly precisely where a welded joint is to be constructed. Thus plastics such as polyamides, polyacetates, polyesters, polyethylenes, polypropylenes, polycarbonates, polyolefins which frequently cannot be joined by means of adhesive can be welded durably to one another without problem. Particularly good results are obtained with polypropylenes. Welding different thermoplastic synthetic materials is also feasible. The following table provides an overview of the plastics which can be employed according to the current state of the art. In this the heading "Appearance" relates to the visible light range and "coloured" refers to variants of the plastic in question coloured by added colorants. In the new method exploiting the intrinsic

absorption by thermoplastic synthetic materials of laser light having a wavelength of approximately 2 μm the added colorants behave in neutral manner. Thus, using the new method plastics in particular can be welded which in the wavelength range of visible light are transparent or translucent. Colorants and other additives, however, may be added to plastics for other reasons. The handling of the laser light having a wavelength of approximately 2 μm is free of problems. It can be guided in low-water or water-free quartz-quartz fibres without excessive attenuation even over relatively large lengths of fibre. In this wavelength range focusing of the laser light onto a movable point or a line or also the non-focused projection of the laser light onto a line are possible with customary optics so that even very fine welded joints can be constructed. This is possible down to a width of 0.1 mm. By means of the new method the welded joints joining the two workpieces are constructed preferably with a width of 0.7 to 2 mm. Welded joints having greater widths are also possible without further ado. Thicknesses of material in the two workpieces are typically between 50 μm and 5 mm, wherein the main focus is on films 0.2 to 2 mm thick. When the workpieces are to be welded with a butt joint their material thickness exactly matches the width of the welded joint. Suitable material thicknesses for butt-welding start at 0.5 mm. By comparison with the absorption length of laser light of wavelength 2 μm in thermoplastic synthetic materials of about 1 to 10 mm depending on the material suitable material thicknesses in the region of the welded joint are of the same order of magnitude or are up to approximately an order of magnitude smaller, whereby although a lower power yield of the laser light is then achieved this is compensated by a particularly homogeneous distribution of heating over the depth of the region exposed to the laser light.

Table

Plastic	Appearance
PS	Transparent or coloured
PMMA	Transparent or coloured
PC	Transparent or coloured
PE	Natural-coloured or coloured
PA	Natural-coloured or coloured
POM	Natural-coloured or coloured
SAN	Natural-coloured or coloured
ABS	Natural-coloured or coloured
PP	Natural-coloured or coloured
SB	Natural-coloured or coloured
PVC	Natural-coloured or coloured
PET	Natural-coloured or coloured
PSU	Natural-coloured or coloured
PBT	Natural-coloured or coloured
TPE	Natural-coloured or coloured

Using the new method two workpieces made of plastic can welded in overlapping manner to one another, whereby the laser light is directed transversely relative to the workpieces. Typically the laser light heats the workpieces on both sides of the contact region, whereby any weakening due to absorption in the region of the rear workpiece can be compensated by a reflector arranged behind this workpiece. The reflector itself is not critical since it is not itself heated by the laser light. It may even be cooled during welding.

Using the new method it is also possible in particular to weld two plastic workpieces together with a butt joint. In doing so the laser light is directed onto both workpieces in a definedly limited, typically very narrow region parallel to the plane of the butt joint. The narrow sides of the work pieces in contact

with one another are heated up by the laser light over the entire depth of the butt joint. Here too a reflector can again compensate any weakening of the laser light by absorption in the direction of the thickness of the butt joint. A particular advantage of the new method by comparison with the state of the art is the possibility of butt-welding both relatively thin films and relatively thick workpieces.

During welding in the region of the required welded joint the workpieces can be arranged between holding elements of which at least one allows the laser light to pass through. The other holding element can be the aforementioned reflector. Both holding elements can be cooled during welding so that the effective heating of the workpieces is concentrated onto an inner region. This is useful in the planar welding of plastic films for example. When constructing a butt joint which should extend over the entire thickness of the butt ends the holding elements must not be cooled so much that the workpieces are no longer plasticised in the vicinity of the holding elements.

The new method, however, may also be carried out completely without contact, whereby the workpieces are laid bare in the region of the required welded joint during welding.

In the new method the laser light can be directed in the form of a spot onto the workpiece or workpieces composed of thermoplastic synthetic material by means of a waveguide. Accordingly, the welded joint when joining two workpieces can have a very complex geometric shape as long as the waveguide can be guided in the direction thereof. This, however, can be done without problem using simple, commonly employed positioning devices.

The laser light, however, can also be guided over a relatively large linear region of a desired weld on the workpieces composed of thermoplastic synthetic material. This is possible, for example, using a waveguide plate on one narrow side of which a plurality of lasers is arranged while the opposite narrow side is arranged to fit against one or both of the workpieces. The laser light is held in the waveguide plate by total reflection and the intensity of the laser light is homogenised over the width of the plate.

The device of the type described at the outset is characterised according to the invention in that the laser emits the laser light at a wavelength of 1.8 to 2.2 µm. Such lasers are disclosed, for example, in DE-UM 296 21 859.6. The laser described there having a wavelength of about 2 µm are particularly well suited to carrying out the method. These are in particular diode-pumped Tm: YAG-Tm, Ho: YAG, Tm: YLF or Tm, HO: YLF lasers. These solid lasers are for their part already comparatively inexpensive. Moreover, a suitable diode laser may also be used which emits the laser light at a wavelength of 2 µm. The laser light at the wavelength of 2 µm can additionally be guided and focused at low cost. It further turns out that by comparison with a corresponding device from the state of the art having a Hd: YAG laser a laser having a luminous power which is approximately an order of magnitude lower is sufficient since its laser light is surprisingly effective and heats up the plastic in the relevant areas of the workpiece or workpieces in concentrated manner. Nevertheless, despite the lower luminous power, within short exposure times to the laser light having a wavelength of approximately 2 µm marked heating of the thermoplastic synthetic material occurs which as a result allows high welding speeds with simultaneously high quality of the welded joints produced. In the preferred

embodiment of the new device the laser is a continuously emitting line-focus laser.

The invention is explained and described in more detail below with reference to exemplified embodiments. The drawing shows:

Fig 1 the set-up in principle for carrying out the new method;

Fig 2 a first embodiment of the new method;

Fig 3 a modification of the embodiment of the new method shown in Fig 2;

Fig 4 a second embodiment of the new method;

Fig 5 a modification of the embodiment of the new method shown in Fig 4;

Fig 6 a second view of the modification of the second embodiment of the new method shown in Fig 5; and

Fig 7 details of a device for a further modification of the embodiment of the method shown in Figs 5 and 6.

Fig 1 shows a laser 1, which is a diode-pumped Tm: YAG solid laser emitting laser light 2 at a wavelength of 2 μm. The laser light 2 is focused by a lens 3 into a waveguide 4. The waveguide is a water-free quartz-quartz fibre. The waveguide exhibits only low attenuation of the laser light 2 even in the case of relatively long fibre lengths. The laser light 2 re-emerging from the waveguide 4 is transformed by an optical system 5 and then strikes a workpiece 6 composed of thermoplastic synthetic material, a polyolefin for example. The laser light 2 is absorbed in a welding region 19 of the

workpiece 6 over an absorption length of several mm, ie converted into heat.

The heating of a lamellar workpiece 7 of another lamellar workpiece 8 located therebehind, both composed of thermoplastic synthetic material, is utilised in the arrangement shown in Fig 2 for the planar joining of the workpieces 7 and 8 by a welded joint 9 formed in the heated welding region. In doing so the workpieces 7 and 8 are welded without contact, ie the workpieces 7 and 8 are completely free in the region of the welded joint 9 and at a distance to the optical system 5.

In the embodiment shown in Fig 3 the optical system 5 is dispensed with. Instead the waveguide 4 fits directly against a quartz glass plate 10 which forms a first holding element 11 for the pair of workpieces 7 and 8 to be bonded flat to one another. To the rear of the workpieces 7 and 8 a second holding element 12 in the form of a reflector 13 is provided. The laser light 2 emanating from the waveguide 4 passes through the quartz glass plate 10 and is then gradually absorbed by the workpieces 7 and 8, whereby the workpieces 7 and 8 are heated in the welding region 19, ie in the region of the required welded join 9. the remainder of the laser light 2 striking the reflector 13 is reflected back onto the workpieces 8 and 7 as a result of which any non-uniform distribution of the heating of the workpieces 7 and 8 over the welding region 19 due to progressive absorption is compensated at least in part. The rate of plasticisation of the plastic at the outer surfaces of the workpieces 7 and 8 is of the same order of magnitude as plasticisation in the region where the workpieces 7 and 8 are in contact with one another. This alone makes it possible to move the holding elements 11 and 12 apart very quickly after the welded joint 9 has been constructed without any damage to the weld. In addition, it is possible to cool the holding

elements 11 and 12 continuously since heating of the workpieces 7 and 8 in the region of contact with the holding elements 11 and 12 is unnecessary for forming the welded joint 9.

Fig 4 shows a different embodiment for welding two workpieces 7 and 8 using laser light 2. The workpieces 7 and 8 composed of thermoplastic synthetic material are here arranged edge to edge. The laser light 2 from the optical system 5 is directed onto the workpieces 7 and 8 in such a way that both workpieces 7 and 8 are heated over the entire thickness of the butt joint 14 and hence of the required weld 9. This possible without problem starting at a wavelength of the laser light 2 of 2 µm for a material thickness of the workpieces 7 and 8 of up to several mm.

While in Fig 4 the workpieces 7 and 8 are not guided or held in the region of the welded joint 9, in Fig 5 support is provided at the rear by a holding element 12 constructed as a reflector 13. Arranged on the admission side of the laser light is a quartz glass plate 15 whose narrow side lies opposite the holding element 12. The quartz glass plate 15 serves as waveguide 4 for the laser light 2 which here is directed into the quartz glass plate 15 directly from the lasers 1 constructed as diode lasers 16 on the side of the quartz glass plate 15 opposite the reflector 13. The laser light 2 is guided by total reflection in the quartz glass plate 15, whereby its intensity distribution is simultaneously homogenised over the width of the quartz glass plate 15 and it then strikes the workpieces 7 and 8 in the region of the butt joint 14, ie in the welding region 19 or the desired welded joint 9.

Fig 6 shows the arrangement in Fig 5 from a viewing direction running at right angles to that of Fig 5 and allows the plurality of diode lasers 16 to be seen.

In Figs 5 and 6 the contact surface of the quartz plate 15 on the workpieces 7 and 8 is flat. Fig 7 shows the case of a complex shape for the desired welded joint in that the narrow side of the quartz plate 15 located opposite the diode lasers 16 exhibits a complicated curvilinear shape. The use of a quartz plate 15 for light guidance is always useful when comparatively broad welded joints are to be produced and when a large number of identical welded joints is to be constructed. Cases of changing geometries of the welded joints and particularly when narrow welded joints are required are easier to deal with using the arrangement shown in Figs 1-4.

Claims

1. Method for welding thermoplastic synthetic materials using laser light, wherein the laser light is directed into a welding region of one workpiece or a plurality of contiguous workpieces composed of thermoplastic synthetic material, characterised in that the laser light (2) has a wavelength of 1.8 to 2.2 µm and that at this wavelength the thermoplastic synthetic materials have an intrinsic absorption with an absorption length of 1 to 10 mm.

2. Method according to Claim 1, characterised in that the thermoplastic synthetic material from which the two workpieces (7, 8) are constructed is transparent or translucent in the wavelength range of visible light.

3. Method according to Claim 1 or 2, characterised in that the laser light (2) is directed into the welding region by means of an optical system (5) and/or a waveguide (4).

4. Method according to Claim 1, 2 or 3, characterised in that in the welding region a welded joint joining the two workpieces (7, 8) having a width of 0.1 to 5 mm, preferably having a width of 0.7 to 2 mm, is formed.

5. Method according to any of Claims 1 to 4, characterised in that the two workpieces (7, 8) have a thickness ranging from 50 µm to 5 mm, particularly from 0.2 to 2 mm.

6. Method according to any of Claims 1 to 5, characterised in that during welding in the region of desired welded joint (9) the workpieces (7, 8) are arranged between holding elements (11, 12) of which at least one allows the laser light (2) to pass through.

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7. Method according to any of Claims 1 to 6, characterised in that by means of the waveguide (4) the laser light (2) is brought directly to the workpiece or workpieces (7, 8) composed of thermoplastic synthetic material.

8. Method according to any of Claims 1 to 7, characterised in that the laser light (2) is directed into a plate-shaped waveguide (4) and by means of said waveguide is guided over a linear welding region on the workpiece or workpieces (7, 8) composed of thermoplastic synthetic material.

9. Device for welding thermoplastic synthetic materials using laser light according to any of Claims 1 - 8 comprising a laser as light source for the laser light and comprising an optical system and/or a waveguide for directing the laser light into a welding region of a workpiece or a plurality of contiguous workpieces composed of thermoplastic synthetic material, characterised in that the laser (1) emits the laser light (2) at a wavelength of 1.8 to 2.2 µm.

10. Device according to Claim 9, characterised in that on the rear side of the workpieces (7, 8) opposite the optical system (5) or the waveguide (4) a holding element (12) in the form of a reflector (13) is provided which reflects the remainder of the laser light (2) passing through the workpieces (7; 8) back onto the workpieces (7, 8), whereby any non-uniform heating of the workpieces (7, 8) over the welding region due to the progressive intrinsic absorption is compensated at least in part.

11. Device according to Claim 9 or 10, characterised in that the laser (1) is a, particularly diode-pumped, Tm: YAG, a

Tm, Ho: YAG, a Tm: YLF or a Tm, Ho: YLF laser or a diode laser (16).